

Stability, Depletion and Restoration of Seagrass Beds*

A. W. D. LARKUM and R. J. WEST

LARKUM, A. W. D., & WEST, R. J. Stability, depletion and restoration of seagrass beds. *Proc. Linn. Soc. N.S.W.* 106 (3), (1982) 1983: 201-212.

The hypothesis that seagrasses are well adapted to the environment in which they live is questioned. Evidence for instability in seagrass beds is documented. Good evidence for depletion of seagrass beds from natural causes exists. In addition it is clear that man-induced depletion has been very severe in many populated coastal areas. The causes of instability in seagrass beds need to be understood both as regards the prevention of further depletion and the restoration of seagrasses in depleted areas. Several techniques have been used successfully for the restoration of seagrasses in small scale experiments but these are expensive and labour-intensive.

A. W. D. Larkum, *School of Biological Sciences, University of Sydney, Sydney, Australia 2006*, and R. J. West, *N.S.W. State Fisheries, 211 Kent Street, Sydney, Australia 2000* (formerly *School of Biological Sciences, University of Sydney*); manuscript received 19 May 1981, accepted for publication in revised form 16 December 1981.

INTRODUCTION

Seagrasses are angiosperms with a rooted rhizome system which limits their distribution generally to unconsolidated sedimentary substrates in relatively calm waters (*Thalassodendron pychirizum* which grows on rocky reefs in Western Australia (Cambridge, 1975) is an exception to this rule). This distribution, in turn, has a special significance for both depletion and restoration, for it means that the favoured sites for seagrasses — estuaries and sheltered embayments — are also the favoured sites for human settlement and activity. As a result there has in the past been much depletion of seagrass beds (Phillips, 1978). However it should be pointed out that it is only recently that man has had any real impact on seagrasses and it is really only the current life styles of world civilizations that are inimical to co-existence at such sites of seagrasses and people.

With the growing awareness of the biology of seagrasses has also come an awareness of the economic importance of seagrasses in a variety of ways (see e.g. Thayer *et al.*, 1976; Phillips, 1978). And out of this have come a number of attempts to restore seagrasses to depleted areas (see Table 1).

However, perhaps the best place to start is on the subject of the stability of seagrass ecosystems in their natural state, since our ideas on the ability of seagrass communities to withstand man-induced impacts depend on this crucial point.

STABILITY OF SEAGRASS BEDS

Introduction

Seagrasses it has been claimed are well adapted to the environment in which they live (e.g. den Hartog, 1979). The supporting evidence for this statement is not completely convincing. Resolution of this matter is very important since on it rests the degree of stability which may be expected from 'natural' seagrass beds and on this in turn rest any assumptions that may be made as to the cause of depletions of beds subjected to man-induced impacts.

* A paper presented at the Australian Seagrass Workshop, University of Sydney, 1981.

Seagrasses are certainly adapted to their environment otherwise they would not be there. The real question to ask is 'are they *well* adapted?' This is a difficult question to answer. It could be argued that the lack of speciation within seagrasses is a sign of poor fitness. Seagrasses probably evolved early in the evolution of angiosperms; but whereas there are approximately 300,000 species of flowering plants there are only 50 odd species of seagrasses. The counter-argument would be that seagrasses are so well adapted to their environment that further adaptation and speciation has been unnecessary. However this sort of argument is unsatisfactory in the light of the vast speciation in terrestrial grasses, freshwater macrophytes and reef fish (Ehrlich, 1975) to take but a few examples. Furthermore the recent documentation of speciation in *Posidonia* (Cambridge and Kuo, 1979) in south western Australia indicates that speciation has taken place in an area which appears to be ideal for the growth of seagrasses.

A number of inherent weaknesses may exist in the strategy of a submersed marine angiosperm. These weaknesses include:—

- 1) sexual propagation
- 2) vegetative propagation
- 3) occlusion of leaves by epiphytes
- 4) internal aeration
- 5) salinity control and turgor regulation
- 6) susceptibility to microbial attack
- 7) requirement for moderately high light environments.

At present there are few hard facts about any of these in relation to the 'fitness' of seagrasses. Johnston (1979) has made the interesting suggestion that the high leaf productivity of seagrasses in comparison with other plants is a result of the need to provide new photosynthetic tissue as the older parts of the leaves become overgrown by epiphytes and epizoids. Despite the fact that seagrass leaf productivity is not exceptional (terrestrial tropical grasses such as sugar cane and napier grass have a productivity several fold higher — see Boardman and Larkum, 1974), the suggestion has some merit and if it is true leads to the constraint that seagrasses have less energy to devote to sexual and vegetative propagative mechanisms. As regards salinity control, Tyerman (1979) has shown that the leaf meristem tissue is hypotonic to seawater and further experiments (unpublished) have shown that exposure of the meristem to seawater leads to its death. Thus mechanical damage of the sheath due to wave action, disease, or animal attack (and of course human activities such as bottom trawls or army 'ducks') can have serious consequences for seagrasses. Internal aeration does not apparently pose any problems for seagrasses; freshwater macrophytes which in terms of speciation are much more successful than seagrasses seem to cope with this constraint. Nevertheless the necessity of having rhizomes and roots in an anaerobic environment must place constraints on the growth and productivity of such a plant and must make it more susceptible to microbial attack. Presumably the high concentration of phenolics and other aromatic compounds in the roots and rhizomes of seagrasses (Cariello and Zanetti, 1979) is an antibacterial response.

Evidence for instability in seagrass beds

The best example of instability in seagrass beds is the 'wasting disease' of *Zostera marina* which caused a near catastrophic decline in stocks of this seagrass in the early 1930s. This example is dealt with further in the next section. However in summary it appears that a slight climatic rise in temperature may have set off the demise (Rasmussen, 1977). Apart from this example there is a great deal of evidence to support recent cyclical changes in stocks of *Zostera marina* (Orth, 1976; den Hartog

1979). In fact McRoy and Bridges (1974) suggested that the 'wasting-disease' of the 1930s was an extreme cycle of a rhythmic oscillation. Evidence for cyclical changes in other seagrasses is not available but this probably reflects the absence of investigations rather than the absence of the phenomenon.

Further evidence for instability can be found in a few studies of various transient phenomena, usually induced by wave-action. Patriquin (1975) has described the 'migration' of blowouts in beds of *Thalassia testudinum* in the West Indies. Storm-generated, crescentic holes in the beds were observed to move shorewards at the rate of ca 0.5 cm/day. It was estimated that any one point would be 'recurrently eroded and restabilized at intervals of the order of 5-15 years'. *Syringodium filiforme* was involved in the recolonization of the blowouts on the leeward slope. Similar blowouts have been described in Western Australia (Cambridge, 1975) in *P. australis* beds (there *Amphibolis antarctica* is involved in the recolonization). In both examples the bed is in a dynamic equilibrium i.e. the seagrass system is able to cope with the factor causing the instability. However it does indicate a rather delicate balance in the system: in both examples the dominant seagrass is absent or very much depleted in more exposed sites. Thus as pointed out by den Hartog (1979) we generally see today the end result of past

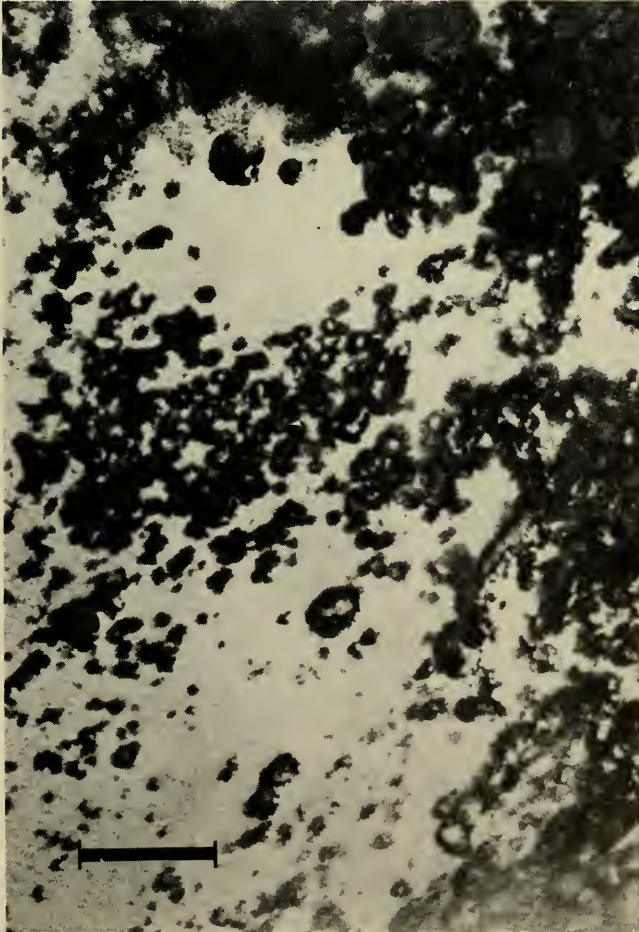


Fig. 1. Rings in *Zostera capricorni* bed in Botany Bay. Scale bar represents 20 m.

evolutionary and successional events and assume that the systems we see are stable. This does not mean however that such events are not going on but they will undoubtedly be more difficult to detect.

Recently we have detected what appears to be a cyclical event in the growth of *Zostera capricorni* (Larkum *et al.*, in prep.). Rings of *Z. capricorni* were observed by means of high-resolution aerial photographs of the northern shore of Botany Bay (Fig. 1). The rings occurred in a shallow region which previously had been an area of largely bare, shifting sand. However after the establishment of the armoured wall for Port Botany, the area became stabilized and wave action was almost eliminated. Under these conditions *Z. capricorni* recolonized most of the area within a few years. It was under these conditions that the rings developed. As can be seen the middle of the rings was bare with only loose sand. Inspection of the rings revealed no apparent cause for the phenomenon. A possible cause for the die-back in the centres could be the depletion of an essential mineral. However this seems unlikely. Another explanation could be that apical meristems, which are critical for seagrass production (Tomlinson, 1974), grow initially in an outward radial direction; eventually the oldest shoots on the rhizomes die and cannot be replaced unless seedlings establish in the centre region or unless one ring grows into another. If this explanation is correct then it will be a further example of the 'apical meristem dependence' of seagrasses and illustrates another possible weakness in seagrass systems. It may well be that the inability of seagrasses to generate secondary apical meristems results in the slow regrowth of eroded areas (West, 1980).

The causes of natural depletion of Seagrass Beds

Research into the natural depletion of seagrass beds has not been extensive in the past and the cause(s) of depletion in any one instance has never been fully established. A number of possible causes have been put forward including disease (Rasmussen, 1977), climatic changes (Rasmussen, 1977; Orth, 1976), natural cycles (McRoy and Bridges, 1974) sediment movement (Kirkman, 1978), salinity changes (Orth, 1976), sea level changes (den Hartog, 1977) and faunal influences (Orth, 1976; Ferguson Wood, 1959).

The most famous example of natural depletion of seagrasses is the 'wasting disease' of *Zostera marina* which resulted in a nearly catastrophic decline in the stocks of this seagrass on both sides of the Atlantic in the early 1930s. Although it is generally agreed that dead plants were attacked by a fungus (*Ophiobolus halimus*) and a slime mold (*Labyrinthula macrocystis*) Rasmussen (1977) has put forward good arguments to suggest that the real cause of the 'disease' was a rise in sea level temperatures in the early 1930s and that the weakened plants were then susceptible to attack by the fungal and slime mold pathogens. Rasmussen (1977) also suggested that seed germination was inhibited at the higher temperatures and that plants growing in brackish water were immune to the 'disease'. Orth (1976) documented a 70% decline in *Zostera marina* in Chesapeake Bay (U.S.A.) from 1972 to 1974 and a virtual disappearance in 1975. This period was accompanied by a rise in average temperatures and a marked rise in water temperatures (Orth, 1976, fig. 7).

If the arguments of Rasmussen are accepted then the growth of *Z. marina* must be seen as a finely balanced process in which temperature, salinity and susceptibility to pathogen attack are finely balanced.

There are two examples of apparently natural depletion of seagrasses in Australia. One is at Corner Inlet, Victoria, which is the only site in continental Victoria where *Posidonia australis* occurs. Large beds have existed there in the past, as evidenced by fibre remains, but in recent years the extent of the beds has decreased (Poore, 1978).

Sedimentation in the region has caused a general rise of the seabed in the region and this in turn may have altered the salinity regime of the area (*P. australis* is a strictly stenohaline species). However the exact cause of the decline is not known. One might more profitably enquire as to why *P. australis* is absent from the remainder of the coast of Victoria but occurs at Eden in N.S.W. and after Port MacDonnell in South Australia.

The second example is the depletion of *Zostera capricorni* in northern areas of Moreton Bay (Kirkman, 1978). This depletion seems to have occurred as a result of sand inundation at a rate faster than the upward growth of the plants. At the same time adjacent healthy beds were subject to increased grazing which contributed to the overall depletion.

TABLE 1
Man-induced impacts affecting seagrass communities

Impact	Seagrass community	Place	Effect	Reference
Turbidity associated with eutrophication	<i>Posidonia oceanica</i>	S. France	Large-scale depletion at lower limit	Meinesz & Laurent, 1976
	<i>Posidonia australis</i>	Cockburn Sound, W.A.	Large-scale depletion	McComb <i>et al.</i> , 1981
	<i>Posidonia australis</i>	Botany Bay	Loss of deeper beds	Larkum, 1976b.
	<i>Thalassia testudinum</i>	Florida	Large-scale depletion	Taylor <i>et al.</i> , 1973
	<i>Thalassia testudinum</i>	Virgin Islands	Local depletions	Dong <i>et al.</i> , 1972 Nichols <i>et al.</i> , 1972
	<i>Zostera capricorni</i> / <i>Ruppia spiralis</i>	Tuggerah Lakes, NSW	Loss of deeper beds	Higginson, 1971
Turbidity associated with dredging	<i>Thalassia testudinum</i>	Virgin Islands, West Indies	Depletions	Van Eepoel <i>et al.</i> , 1971
	<i>Thalassia testudinum</i>	St. Thomas, West Indies	Depletions	Grigg, 1970
Hydraulic clam dredge	<i>Thalassia testudinum</i> / <i>Halodule beaudettei</i> <i>Syringodium filiforme</i>	Tampa and Tarpen Springs, Florida	Extensive losses	Godcharles, 1971
Dredging and filling	<i>Thalassia testudinum</i>	Boca Ciega Bay, Florida	Local depletions	Taylor & Saloman, 1968
	<i>Thalassia testudinum</i>	Redfish Bay, Texas	Local depletions	Odum, 1963
Sewage effluent	<i>Thalassia testudinum</i>	Biscayne Bay, Florida	Local depletions	McNulty, 1970
	<i>Thalassia testudinum</i>	Florida	Local depletions	Hammer, 1972
	<i>Posidonia oceanica</i>	S. France	Large-scale depletions	Peres & Pickard, 1974
	<i>Posidonia australis</i>	Adelaide S.A.	Severe local depletion	Shepherd, 1970

Hot water effluents	<i>Thalassia testudinum</i>	Florida	Large depletion	Zieman, 1976
		Florida	Large depletion	Thorhaug <i>et al.</i> , 1978
Salinity changes	<i>Thalassia testudinum</i> <i>Halodule beaudettei</i> <i>Syringodium filiforme</i>	Florida	Loss of leaves and some depletion	McMillan & Moseley, 1967
	<i>Thalassia testudinum</i>	Florida	Die-back but recovery	Zieman, 1975
Overgrazing by <i>Lytechinus variegatus</i>	<i>Thalassia testudinum</i>	Florida	Local depletion	Camp <i>et al.</i> , 1972
Oil pollution	<i>Thalassia testudinum</i>	Puerto Rico	Local losses	Diaz-Piferrer, 1962
	<i>Phyllospadix torreyi</i>	Santa Barbara	Local depletion	Foster <i>et al.</i> , 1971
Physical disturbance by boats	<i>Thalassia testudinum</i>	Florida	Small scale losses but spreading	Zieman, 1976
Industrial effluents	<i>Posidonia australis</i>	Cockburn Sound	Local losses	Cambridge, 1975

MAN-INDUCED DEPLETION OF SEAGRASS BEDS

There are a great number of examples of man-induced depletions of seagrass beds (Table 1) and there are a great number of possible or known causes amongst which are the following:—

- 1) turbidity increases associated with dredging,
- 2) turbidity increases associated with industrial or urban influences,
- 3) turbidity increases associated with eutrophication,
- 4) toxic chemicals,
- 5) hot water effluents,
- 6) oil spills,
- 7) activities of commercial fishermen using bottom trawls,
- 8) changes in salinity,
- 9) sewage.

Much of the evidence on these factors comes from overseas studies as can be seen from Table 1, and much of it is less than fully convincing. It relies on field observations and circumstantial evidence. Many of the sites where depletion occurred were subject to multiple impacts and it may not be justified to single out one factor. Clearly careful experiments with proper controls are needed.

In Australia there are a number of published reports on man-induced depletion of seagrass beds (Shepherd, 1970; Higginson, 1971; Cambridge, 1975; Larkum, 1976 a, b; Shepherd and Van der Borch, 1977). In no case, so far has the cause been established categorically except for the mechanical removal of *P. australis* beds in the Spencer Gulf, South Australia. In fact in all of the other examples multiple impacts existed. The most clear-cut case would seem to be the disappearance of *P. australis* near sewage outfalls off the coast of Adelaide (Shepherd, 1970) yet even this has been disputed (Steffensen, unpublished). It would seem that transplant experiments with

proper controls should be able to provide a definitive answer. In Cockburn Sound (McComb *et al.*, 1981), in Botany Bay (Larkum, 1976a, 1976b and unpublished) and in the Tuggerah Lakes increased turbidity would seem to be the most important factor. In Botany Bay wave-action is also a clear-cut factor at some sites (Larkum, 1976b). However at all these places a number of impacts are present. In the Tuggerah Lakes some depletion is almost certainly due to hot-water effluents from electric power stations (Weiner, personal communication).

Poorly documented evidence exists also for the following:

- i) depletion due to oil and dispersants in Botany Bay and,
- ii) depletion due to hot water effluent in Botany Bay (Bunnerong Power Station).

Depletion of seagrasses has almost certainly occurred in Port Phillip, Sydney

TABLE 2

Transplantation of Seagrasses by Various Workers using Various Techniques
(Adapted from Thorhaug and Austin, 1976)

NAA = Naphthylacetic acid

Method	Worker and Publication Date	Place	Anchoring Method	Chemical Additive	Dimensions of Transplant	Success	Species
Plugs	Kelly <i>et al.</i> (1971)	Tampa Bay, Florida	Tin can or Bag	NAA	20 cm ²	Control 40% Exper. 15%	<i>Thalassia testudinum</i>
Plugs	Breedveld (1976)	Tampa, Florida	30 cm substrate into hole	5% NAA 5% Root dip	30 cm Deep post-hole digger	0-100%	<i>Thalassia testudinum</i>
Plugs	Breedveld (1975)	Tampa, Florida	30 cm substrate into hole	5% NAA 5% Root dip	30 cm Deep post-hole digger	100%	<i>Syringodium filiforme</i>
Plug	Kirkman (1976)	Moreton Bay, Australia	Dug holes	None			<i>Zostera capricorni</i>
Plugs	Phillips (1974)	Tampa Bay, Florida	Buried with soil	None	10 cm ²	Some	<i>Halodule wrightii</i>
Plugs	Phillips (1974)	Tampa Bay, Florida	Buried with soil	None	10 cm ²	None	<i>Thalassia testudinum</i>
Plugs & Turfs	Phillips (1980)	Redfish Bay, Texas	Buried with soil	None	60 cm ²	80-100%	<i>T. testudinum</i> <i>H. wrightii</i>
Turfs	Ranwell <i>et al.</i> (1974)	Norfolk, England	Spaded into hole	None	ca22 × 15 × 10 cm deep	Varied	<i>Zostera noltii</i>
Turfs	Ranwell <i>et al.</i> (1974)	Norfolk, England	Spaded into hole	None	ca22 × 10 × 15 cm deep	100% year 1 35% year 2	<i>Zostera noltii</i> <i>Z. marina</i>
Turfs	Larkum (1976)	Botany Bay, Australia	Dug holes	None	50 × 50 cm	50-100%	<i>Zostera capricorni</i> & <i>Posidonia australis</i>
Turions	Kelly <i>et al.</i> (1971)	Tampa Bay, Florida	1. Construction rods 2. Brick pipes	10% NAA	Short shoot and rhizome	18% in some	<i>Thalassia testudinum</i>
Turions	Eleuterius (1975)	Biloxi, Mississippi	Wire-mesh anchor and Construction rod	None	45 × 45 cm	3% 5% None	<i>T. testudinum</i> <i>H. wrightii</i> <i>Cymodocea manatorum</i>
Turions	Phillips (1974)	Whidbey Isle, Washington	Iron pipes and trenches	None	Short shoot and rhizome portion	Dependent on depth 100% to none	<i>Zostera marina</i>
Seeds	Phillips (1974)	Friday Harbor, Washington	Iron rods and trenches	None	Single seeds	None	<i>Zostera marina</i>
Seeds	Thorhaug (1974)	South Biscayne Bay, Florida	Plastic	10% NAA	Single seeds	80%	<i>Thalassia testudinum</i>
Seeds	Thorhaug & Hixon (1975)	North Biscayne Bay, Florida	Plastic peat-pots	10% NAA	Single	15%-55%	<i>Thalassia testudinum</i>

Harbour (and the Parramatta River) and the Brisbane River, but good documentation of these events and their causes is lacking.

It is worth noting in passing that there has been no published work anywhere in the world on the effect of toxic wastes such as heavy metals and chlorinated hydrocarbons on seagrasses or seagrass communities.

Considering the economic importance attached to seagrass beds (see e.g. Thayer *et al.*, 1976; and Phillips, 1978) it is surprising that more public money is not being spent on investigating the causes of the various depletions of seagrasses in Australia. The lack of funding can partly be seen as a result of ignorance and the great expanse of completely untouched seagrass beds in southern and western Australia.

RESTORATION OF SEAGRASS BEDS

Introduction

Restoration of seagrass beds does occur naturally at times, as for instance after the 'wasting disease' of the 1930s. However artificial restoration is an important development that has come about in recent years mainly as a result of man-induced depletions of seagrass beds. For instance in Florida (U.S.A.) real estate development involving dredging of *Thalassia testudinum* meadows resulted in large scale depletion of this seagrass in the 1960s and had the Florida State Board of Conservation setting up a programme to restore this seagrass to several areas (Phillips, 1974). Also in Florida, hot water effluents led to damage of *Thalassia* beds and restoration by transplanting was effected (Thorhaug and Roessler, 1976). In fact the history of transplants goes all the way back to the 'wasting disease' period of the 1930s when rather ineffectual attempts were made to revegetate areas with *Zostera marina* (see Phillips, 1974).

Table 2 lists all published attempts to date to transplant seagrasses.

Techniques

a) Vegetative

Two basic techniques exist. They are:—

- a1) transplantation of seagrass plants without accompanying sediment. The plants (including rhizomes and several shoots) are replanted in sediment of the new site (Phillips, 1974; Larkum, 1976a),
- a2) transplantation of seagrass turfs, i.e. plants are removed *in situ* in undisturbed sediment placed into trays or bags and relocated into excavated holes at the new site (Ranwell *et al.*, 1974; Fuss and Kelly, 1969; Breedveld, 1975). Anchoring may be a problem. Dislodgement may occur as a result of storms or through the activities of fishermen or prawners. A number of devices have been tried. Kelly *et al.* (1971) mention cans, sacking polyethylene, pipes, construction rods and breeze bricks. To this list can be added steel mesh for reinforcing concrete (Larkum, 1976a) and plastic netting (Ranwell *et al.*, 1974).

- b) Seedlings. This method has been pioneered with success by Thorhaug (1974, 1976, 1979).

Results and Discussion

Transplanting of seagrasses by the vegetative method has in most cases met with reasonably good initial success. A great deal depends on the species of seagrass. Pioneer and rapidly growing species may quickly spread out and cover a large area at the new site, e.g. *Zostera noltii* (Ranwell *et al.*, 1974), *Zostera marina* (Phillips, 1974). In this way an area may be 'seeded' with the minimum of work and money. On the other hand with 'climax' species such as *Thalassia testudinum* and *Posidonia* spp. growth rate

may be much slower and replanting might mean the 'sod by sod' coverage described by Thorhaug (1979). In fact Kelly *et al.* (1971) note that regression may occur at transplant sites because of death of older shoots and lack of replacement. This results from the 'meristem dependence' of seagrass populations (Tomlinson, 1974). Few seagrasses have dormant meristems and horizontal vegetative spreading depends on the presence of an apical meristem. In an established seagrass bed there may be many shoots but few apical meristems. Thus in vegetative transplants no apical meristem may be present and expansion growth cannot then occur. Apical meristems can generate from older (short) shoots but this is not common.

Seedlings generate an apical meristem directly and are thus ideal for transplant work providing that large quantities of seeds can be obtained and germinated and provided that these can be sown effectively. With *Thalassia testudinum* this can be done easily and economically (Thorhaug and Austin, 1976). This species also has the advantage that seedlings grow rapidly producing a 'long' shoot and several 'short' shoots within six months. With *Posidonia australis* seedling growth is much slower and production of an apical meristem (within this species the second shoot) does not occur for at least a year (McComb *et al.*, 1981; West, 1980).

Austin in Thorhaug and Austin (1976) has costed the operation of seagrass transplants and for *Thalassia* seedling transplants this works out to be about \$U.S. 13,000 per ha. Ranwell *et al.* (1974) costed their vegetative process at £1,000 per ha. (1973 prices). It would therefore appear that restoration of at least some depleted sites is possible and not outrageously expensive. However in all the successful experiments the sites have not been subject to stresses or impacts (for example the hot water discharge involved in the area of depletion used by Thorhaug (1974) had been discontinued before the transplant experiments were conducted). In areas where man-induced impacts occur and where the most depletions have resulted restoration of seagrass beds may be much more difficult, at least until the major causal factor has been identified and controlled. Nevertheless such situations do provide the opportunity to study the effects of a variety of impacts on seagrasses.

CONCLUSION

Australia is richly endowed with seagrasses both in terms of species and in terms of the extent of seagrass beds. This affords many opportunities for the study of stability/instability, evolutionary changes, successional changes and natural depletions, all of which are in great need of much further research. Seagrass communities may be less stable than they were previously held to be.

The overall wealth of Australian seagrasses may suggest that local depletion of seagrass beds near to several state capitals is unimportant. This may be so but until we know much more about the stability of natural seagrass systems, natural depletions, man-induced depletions and the role of seagrass beds in the natural economy of coastal waters there needs to be a note of caution in any acceptance of local depredations and a positive attitude to the possibility of restoration of seagrass beds. In any event there will probably always exist a need for the restoration of seagrass beds as a result of natural depletions and activities such as dredging, harbour development and offshore mining.

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